Sequence of the Cenozoic Mammalian Faunas of the Linxia Basin in Gansu, China

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Abstract In the Linxia Basin on the northeast margin of the Tibetan Plateau, the Cenozoic strata are very thick and well exposed. Abundant mammalian fossils are discovered in the deposits from the Late Oligocene to the Early Pleistocene. The *Dzungariotherium* fauna comes from the sandstones of the Jiaozigou Formation, including many representative Late Oligocene taxa. The *Platybelodon* fauna comes from the sandstones of the Dongxiang Formation and the conglomerates of the Laogou Formation, and its fossils are typical Middle Miocene forms, such as *Hemicyon*, *Amphicyon*, *Platybelodon*, *Choerolophodon*, *Anchitherium*, and *Hispanotherium*. The *Hipparion* fauna comes from the red clay of the Liushu and Hewangjia Formations, and its fossils can be distinctly divided into four levels, including three Late Miocene levels and one Early Pliocene level. In the Linxia Basin, the *Hipparion* fauna has the richest mammalian fossils. The *Equus* fauna comes from the Wucheng Loess, and it is slightly older than that of the classical Early Pleistocene Nihewan Fauna. The mammalian faunas from the Linxia Basin provide the reliable evidence to divide the Cenozoic strata of this basin and correlate them with European mammalian sequence.

Key words: Linxia Basin, Cenozoic, stratigraphy, mammalian fossil, Gansu, China

1 Introduction

The Linxia Basin is situated in the southeastern part of Gansu Province, China, and it is a flexural basin bounded by the Leijishan fault, North Qinling fault, and the Maxian Mountain (Fang et al., 2003). The lithology and structures of the strata in the Linxia Basin are very close to those in a number of Cenozoic sedimentary basins in central Gansu. All of these small basins are called by a joint name, Longzhong Basin. The Cenozoic strata are very thick and well exposed in the Linxia Basin, with a consecutive sedimentary sequence from the Oligocene to the Holocene. More importantly, these deposits contain abundant mammalian fossils, which provide the reliable evidence to divide and correlate the Cenozoic strata of the Linxia Basin (Fig. 1). However, the understanding for the stratigraphical sequence and age had a lot of contraventions previously, with repeated lithologic names and confused fossil evidence. In the field work of the recent years, we cleaned up the sedimentary sequence in order, and determined again the corresponding geological age of each lithologic unit on the basis of the sufficient evidence of mammalian fossils (Table 1). In the Linxia Basin, the Late Oligocene *Dzungariotherium* fauna, the Middle Miocene *Platybelodon* fauna, the Late Miocene *Hipparion* fauna, and the Early Pleistocene *Equus* fauna are the most abundant.

2 Late Oligocene *Dzungariotherium* fauna

The *Dzungariotherium* fauna of the Linxia Basin comes from the sandstones of the Late Oligocene Jiaozigou Formation (Fig. 2). Qiu et al. (1990) reported the mammalian fossils discovered from Jiaozigou in Dongxiang County, and this fauna included *Gomphotherium* sp., *Dzungariotherium orgosense*, Rhinocerotidae gen. et sp. indet., and *Paraentelodon macrognathus*. But the proboscidean fossil (*Gomphotherium*) is proved to interfuse into the Jiaozigou Fauna. The newly discovered taxa also include *Tsaganomys* sp., *Allacerops* sp., *Aprotodon* sp. and *Schizotherium* sp., and originally Rhinocerotidae gen. et sp. indet. is determined to be *Ronzotherium* sp.

The giant rhinoceros is a representative mammal in Asia, and infrequently discovered in Eastern Europe. The giant rhinoceros was diversified in the middle Oligocene, and it became very advanced in the Late Oligocene. *Dzungariotherium orgosense* was first found from the Junggar Basin in Xinjiang, with a large size, rudimental lower incisors, well-developed antecrochets, and wide foot bones. In Xinjiang, *D. orgosense* coexists with *Lophimeryx*, and the last record of the latter is from the middle late Stampian Age in Europe (Qiu et al., 1990). *Allacerops* was a rhinocerotid form living in the Oligocene of Asia, and it was found from the Oligocene in the

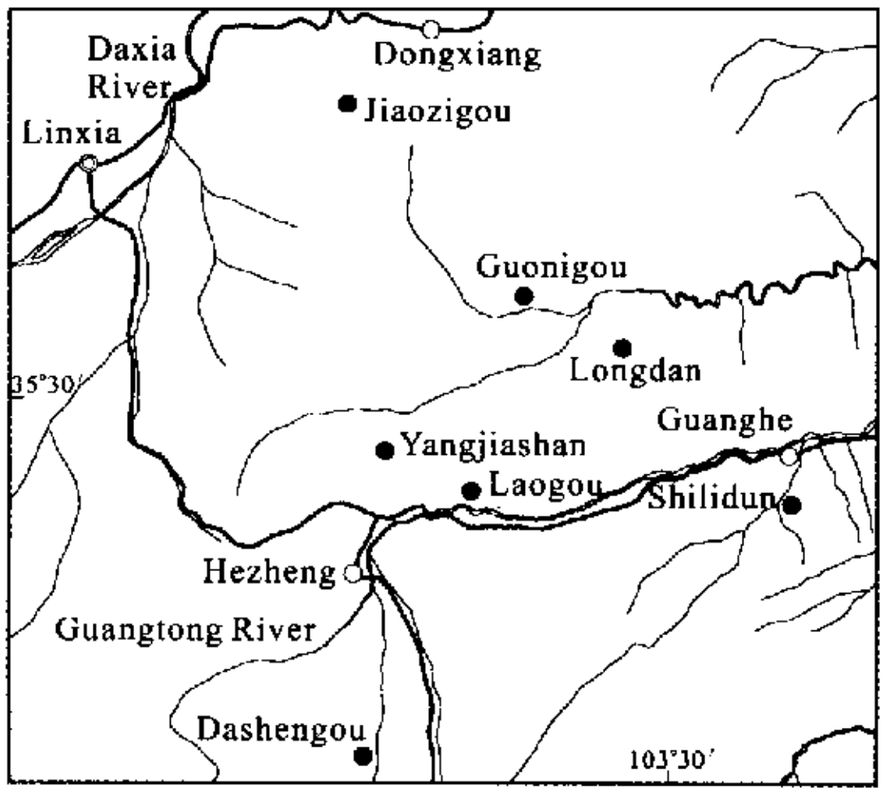

Fig. 1. Representative fossil localities of the Cenozoic in the Linxia Basin.

Lanzhou Basin adjacent to the Linxia Basin (Qiu and Wang, 1999). *Schizotherium* was also a characteristic Oligocene form in China, and it was found from the Oligocene Nanpoping Fauna in the Lanzhou Basin (Qiu et al., 1998). *Aprotodon* was previously found only from Pakistan, Kazakhstan, and the Lanzhou Basin, and it coexisted with the giant rhinoceros in these three regions (Qiu and Xie, 1997) like in the Jiaozigou Formation of the Linxia Basin. *Ronzotherium* was found only in the Oligocene of Eurasia (Heissig, 1969). The entelodont was the most diversified during the Sannoisian and the early-middle Stampian Ages, and *Paraentelodon macrognathus* was very abundant in the Jiaozigou Fauna. *Tsaganomys* appeared first in the late Early Oligocene, and its assured record ended in the early Late Oligocene. As a result, *Tsaganomys* is one of the index fossils for the Asian Oligocene (Wang, 2001). *Tsaganomys* was found from the Oligocene Nanpoping Fauna in the Lanzhou Basin. Apparently, the age of the Jiaozigou Fauna is Late Oligocene.

3 Middle Miocene *Platybelodon* fauna

The *Platybelodon* fauna of the Linxia Basin is represented by the Laogou locality in Hezheng County, mainly from the conglomerates of the late Middle Miocene Laogou Formation, and two sandstone fossil beds of the early Middle Miocene Dongxiang Formation at Dalanggou and Wangshijie in Guanghe County are combined into the Laogou Fauna (Fig. 2). This fauna includes *Alloptox* sp., *A. minor*, *Megacricetodon sinensis*, *Protalactaga tunggurensis*, *Sayimys* cf. *obliquidens*, *Pliopithecus* sp., *Hemicyon teilhardi*, *Amphicyon tairumensis*, *Gobicyon* sp., *Percrocuta tungurensis*, *Pseudaelurus guangheensis*, *Choerolophodon* sp., *Gomphotherium* sp., *Platybelodon grangeri*, *Zygolophodon* sp., *Anchitherium gobiensis*, *Alicornops* sp., *Hispanotherium matritense*, *Calicotherium* sp., *Kubanochoerus gigas*, *Listriodon mongoliensis*, *Dorcatherium* sp., *Moschus* sp., *Palaeotragus tunguensis*, and *Turcocerus* sp. (Guan, 1988; Deng, 2003).

The fossils of the Laogou Fauna are the typical Middle Miocene forms, represented by Tunggurian *Platybelodon* and *Anchitherium* (Qiu and Qiu, 1995). The shared genera between the Laogou and Tunggur Faunas include *Alloptox*, *Hemicyon*, *Amphicyon*, *Platybelodon*, *Zygolophodon*, *Anchitherium*, *Hispanotherium*, *Kubanochoerus*, *Listriodon*, *Palaeotragus*, and *Turcocerus*. *Alloptox* was widespread found from the Middle Miocene faunas in China, such as Tunggur in Inner Mongolia (Young, 1932), Lengshuigou in Lantian, Shaanxi (Li, 1978), Qijia in Minhe, Qinghai (Qiu et al., 1981), and Dingjia'ergou in Tongxin, Ningxia (Wu et al., 1991). *Pliopithecus* existed during MN5-9 in Europe, and it was found from the Dingjia'ergou and Halamagai (Junggar, Xinjiang) Faunas of the Middle Miocene in China (Qiu and Guan, 1986; Wu

Table 1 Divisions of the Cenozoic strata in the Linxia Basin

GPIB, 1965		Xie, 1991		Li et al., 1995		Present paper	
Q_1	Clayey	Q	Loess	Q_1	Dongshan Fm.	Q_1	Wucheng Loess
	Conglomerate			N_2^2	Jishi Fm.	N_2^2	Jishi Fm.
N_2	4th M., Linxia Fm.	N_1^3	Linxia Fm.	N_2^1	Hewangjia Fm.	N_2^1	Hewangjia Fm.
				N_1^3	Liushu Fm.	N_1^3	Liushu Fm.
						N_1^2	Laogou Fm.
	3rd M., Linxia Fm.	N_1^2	Dongxiang Bed		Dongxiang Fm.		Dongxiang Fm.
				N_1^2	Shangzhuang Fm.		
	2nd M., Linxia Fm.	N_1^1	Jiaozigou Fm.	N_1^1	Zhongzhuang Fm.	E_3^2 - $?N_1^1$	Jiaozigou Fm.
	1st M., Linxia Fm.			E_3^2	Tala Fm.	$?E_3^1$	Tala Fm.

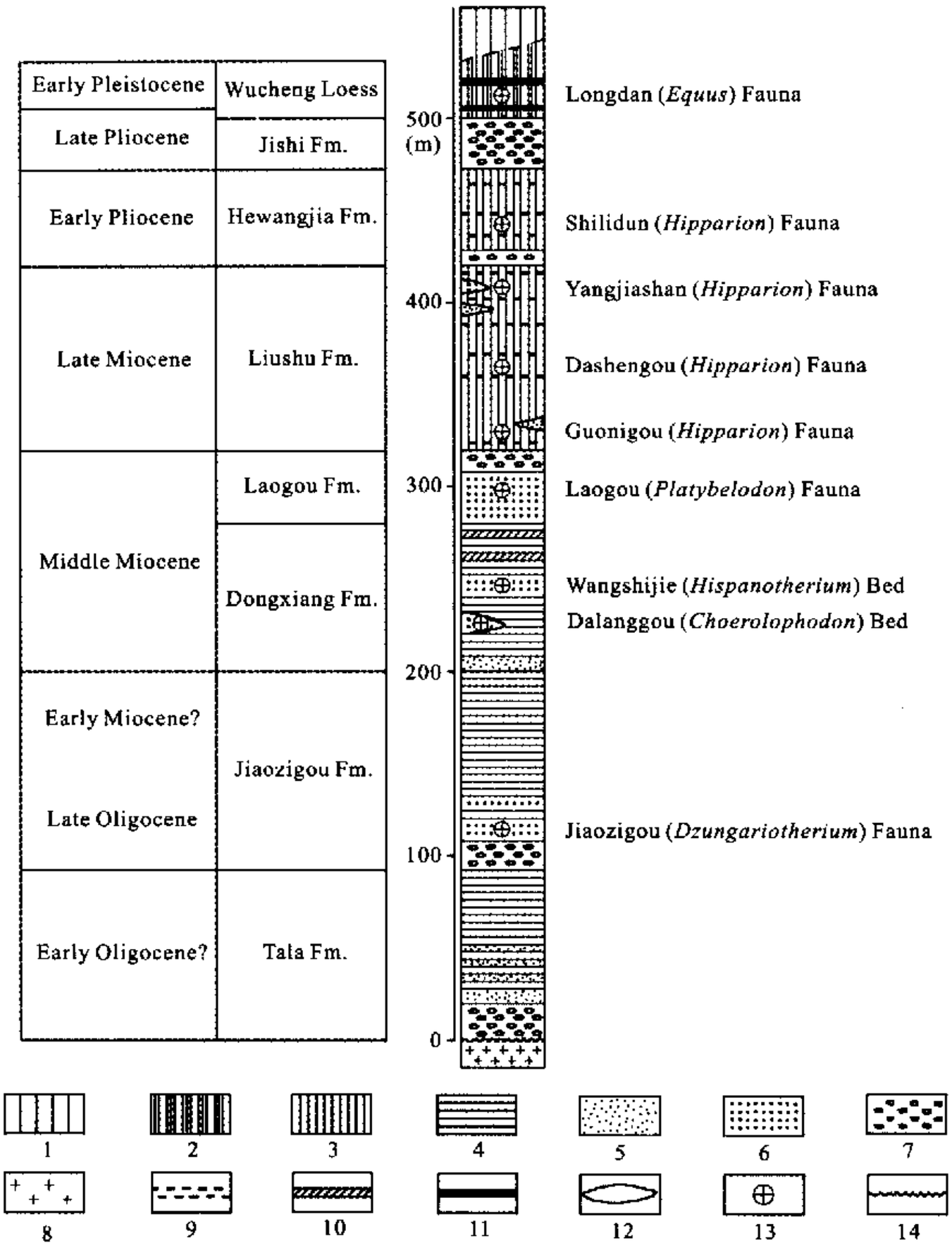

Fig. 2. Cenozoic stratigraphic column in the Linxia Basin.
1. Malan loess; 2. Wucheng loess; 3. Red clay; 4. Mudstone; 5. Siltstone; 6. Sandstone; 7. Conglomerate; 8. Granite; 9. Carbonate concretions; 10. Marlite; 11. Paleosol; 12. Lenticular body; 13. Fossil bed; 14. Unconformity.

et al., 2003). In Eurasia, *Hispanotherium matritense* was found in Spain, Portugal and France of Europe, and Turkey, Pakistan, Mongolia and China of Asia. In China, *H. matritense* distributed widespread, found from the Middle Miocene Dingjia'ergou, Lengshuigou and Erlanggang (Fangxian, Hubei) Faunas (Zhai, 1978; Yan, 1979; Guan, 1988). *H. matritense* is smaller than *H. tungurense* of the Tunggur Fauna (Cerdeño, 1996; Deng, 2003). *Alicornops* distributed widespread in Europe during MN6-10 (Cerdeño and Sánchez, 2000), and it was found from the Middle Miocene strata in Turkey (Heissig, 1976). *Kubanochoerus* appeared in the strata of MN6 in Caucasia, and it was found at Dingjia'ergou, Tunggur and Koujiacun (Lantian, Shaanxi). Therefore, *Kubanochoerus* is a typical Middle Miocene form.

4 Late Miocene-Early Pliocene *Hipparion* fauna

Qiu et al. (1987b, 1988, 1991) described the Late Miocene mammalian fossils discovered from the Linxia Basin, including *Dinocrocuta gigantea*, *Agriotherium inexpetans*, *Hipparion* sp., *Acerorhinus hezhengensis*, *Chilotherium* sp., *Cervavitus* sp., and *Honanotherium* sp. Since recent years, we have found more abundant fossils of the *Hipparion* fauna from the red clay of the Late Miocene

Liushu Formation and the Early Pliocene Hewangjia Formation. These fossils can be distinctly divided into four levels, represented by Guonigou (Dongxiang County), Dashengou (Hezheng County), Yangjiashan (Hezheng County), and Shilidun (Guanghe County) respectively (Fig. 2).

4.1 Guonigou Fauna

The Guonigou Fauna comes from the lower part of the Liushu Formation, and its fossils include *Dinocrocuta gigantea*, *Machairodus* sp., *Tetralophodon* sp., *Hipparion dongxiangense*, *Parelasmotherium simplum*, *P. linxiaense*, and *Shaanxispira* sp.

The Guonigou Fauna is characteristic of early Late Miocene age. *Dinocrocuta gigantea* is a representative of the early *Hipparion* fauna in Asia, and it is discovered mainly from the early Late Miocene, corresponding to the European Vallesian Age or MN9-10 (Howell and Peter, 1985). The materials discovered in China show the same trend. The fossils of *Dinocrocuta* were found from Bahe in Lantian, Shaanxi (Liu et al., 1978; Zhang et al., 2002) and Bulong in Biru, Tibet (Zheng, 1980), and they came from strata corresponding to the Vallesian (Li et al., 1984; Qiu and Qiu, 1995). *Dinocrocuta* was also reported from Songshan in Tianzhu, Gansu (Zheng, 1982) and Laogaochuan in Fugu, Shaanxi (Xue et al., 1995; Zhang and Xue, 1996), and the two localities were considered to be equivalent to the European Turolian Age. However, the specimens of the former came from a drug store, and the age of the latter need further studies. The size of *H. dongxiangense* is smaller than that of *H. parvum*, the smallest known species of *Hipparion* in China, and its characteristic structures of the hypocone and the hypocone groove frequently occur among the Middle Miocene hipparionines from North America, but are infrequent among the late hipparionines. As a result, *H. dongxiangense* indicates an earlier age (Qiu and Xie, 1998). *Parelasmotherium* is more primitive than *Sinotherium*, the representative taxon in the Baode Fauna, and the former is the earliest member of the giant elasmothere developing toward hypsodont teeth (Qiu and Xie, 1998; Deng, 2001c). *Shaanxispira* also appeared in the Bahe Fauna (Liu et al., 1978; Zhang et al., 2002). Consequently, the age of the Guonigou Fauna should be early Late Miocene, corresponding to the Vallesian Age of the Europe. According to this correlation, the Qaidam Fauna (Bohlin, 1937) may have the same evolutionary level with the Guonigou Fauna (Qiu and Qiu, 1995; Qiu et al., 1999). However, both faunas do not have many taxa, and the shared genera include only *Tetralophodon* and *Hipparion*, whose materials are too rare to be certain about their specific status.

4.2 Dashengou Fauna

The Dashengou Fauna comes from the middle part of the Liushu Formation. Qiu et al. (1987b, 1988, 2000) described *Acerorhinus hezhengensis*, *Dinocrocuta gigantea*, and *Hezhengia bohlini* in the Dashengou Fauna, and other taxa include *Pararhizomys hipparionum*, *Promephitis* sp., *P. hootoni*, *Melodon majori*, *Sinictis* sp., *Ictitherium* sp., *Hyaenictitherium wongii*, *H. hyaenoides*, *Machairodus palanderi*, *Felis* sp., *Tetralopodon exoletus*, *Hipparion chiai*, *H. weihoensis*, *Chilotherium wimani*, *Iranotherium morgani*, *Chleuastochoerus stehlini*, *Dicrocerus* sp., *Samotherium* sp., *Honanotherium schlosseri*, *Gazella* sp., and *Miotragocerus* sp.

The Dashengou fauna is still composed of early Late Miocene taxa, such as *Dinocrocuta gigantea*, which first appeared in the Guonigou Fauna. Other important components of the Bahe Fauna are relatively richly represented in the Dashengou Fauna, such as *Hipparion weihoense* and *H. chiai*. These two species of *Hipparion* have a large size, deep preorbital fossae far from the orbit, and narrow and long protocones. These characters show that both of them apparently belong to the *H. primigenius* group, and the hipparionines of this group in Europe and Africa are predominantly Vallesian in age (Qiu et al., 1987a). The shared species in the Bahe and Dashengou Faunas also include *Tetralophodon exoletus* and *Chleuastochoerus stehlini* (Liu et al., 1978). *Hezhengia bohlini* is one of the most typical taxa in the Dashengou Fauna. The horncores of *Hezhengia* are obviously less specialized than those of the middle-late Late Miocene ovibovines, such as *Plesiaddax*, and its premolars are relatively long, with strong ribs and styles. Therefore, the primitive characters of *H. bohlini* imply that its age should be earlier than that of the middle-late Late Miocene ovibovines (Qiu et al., 2000). *Acerorhinus hezhengensis* has a very narrow mandibular symphysis and little separated parietal crests to form a high sagittal crest, and thus it is close to *A. tsaidamensis* in the Qaidam Fauna but different from *A. palaeosinensis* in the Baode Fauna (Qiu et al., 1987b). Judging from the whole components of the Dashengou Fauna, it should be correlated to the late Vallesian Age of Europe. Besides the Bahe Fauna, the Lamagou Fauna in Fugu, Shaanxi (Xue et al., 1995) may be contemporaneous with the Dashengou Fauna. There are many common taxa between the Lamagou and Dashengou Faunas, including *Dinocrocuta gigantea*, *Hyaenictitherium wongii*, *Hipparion chiai*, *Chilotherium wimani*, *Samotherium* sp., and *Miotragocerus* sp. Moreover, *Acerorhinus fuguensis* from Lamagou also is very close to *A. hezhengensis* from the Dashengou Fauna (Deng, 2000).

4.3 Yangjiashan Fauna

The Yangjiashan Fauna comes from the upper part of the Liushu Formation, and its fossils include *Hystrix gansuensis*, *Pararhizomys hipparionum*, *Simocyon* sp., *Parataxidea sinensis*, *Promephitis* sp., *P. hootoni*, *Plesiogulo* sp., *Ictitherium* sp., *Hyaenictitherium wongii*, *H. hyaenoides*, *Adcrocuta variabilis*, *Machairodus* sp., *M. palanderi*, *Metailurus* sp., *M. minor*, *Felis* sp., *Hipparion* sp., *H. coelophyes*, *H. dermatorhinum*, *Acerorhinus hezhengensis*, *Chilotherium wimani*, *Dicerorhinus ringstromi*, *Ancylotherium* sp., *Chleuastochoerus stehlini*, *Microstonyx major*, *Metacervulus* sp., *Cervavitus novorossiae*, *Honanotherium schlosseri*, *Palaeotragus microdon*, *Miotragocerus* sp., *Sinotragus* sp., *Protoryx* sp., and *Gazella* sp.

In the Yangjiashan Fauna, the early Late Miocene representatives, such as *Dinocrocuta gigantea* and *Hezhengia bohlini* have disappeared. The Yangjiashan Fauna is similar to the Baode Fauna, the typical fauna of the late Late Miocene in China. They share many taxa, including *Simocyon* sp., *Plesiogulo* sp., *Parataxidea sinensis*, *Promephitis hootoni*, *Hyaenictitherium wongii*, *H. hyaenoides*, *Adcrocuta variabilis*, *Machairodus* sp., *Metailurus minor*, *Dicerorhinus ringstromi*, *Chleuastochoerus stehlini*, *Microstonyx major*, *Cervavitus novorossiae*, *Palaeotragus microdon*, *Honanotherium schlosseri*, and *Sinotragus* sp. Like the Baode fauna, rhinocerotids are absolutely dominant in the Yangjiashan Fauna, although both of them are named as the *Hipparion* faunas. On the other hand, the more primitive *Chilotherium wimani* in the Yangjiashan Fauna is replaced by the more derived *C. anderssoni* in the Baode Fauna. The primitive characters of *C. wimani* include the low position of orbit, well-developed supraorbital tubercle, weak postorbital process, concave dorsal skull profile, little separate parietal crests, narrow braincase, and strong paracone rib on premolars (Deng, 2001a, b), while the derived characters of *C. anderssoni* include the high position of orbit, absence of supraorbital tubercle, well-developed postorbital process, flat dorsal skull profile, broadly separate parietal crests, rounded braincase, and weak or absent paracone rib on premolars (Ringström, 1924). *Hystrix*, *Ancylotherium* and *Metacervulus* appeared in the Yangjiashan Fauna. In conclusion, the Yangjiashan Fauna may be appreciably earlier than the Baode Fauna.

4.4 Shilidun Fauna

The Shilidun Fauna comes from the Hewangjia Formation, and its fossils include *Hystrix gansuensis*, *Promephitis* sp., *Chasmaporthetes* sp., *Hyaenictitherium wongii*, *Hipparion* sp., *Shansirhinus ringstromi*, *Cervavitus novorossiae*, *Palaeotragus* sp., *Sinotragus* sp., and *Gazella* sp.

Chasmaporthetes sp. and *Shansirhinus ringstromi* newly appeared in the Shilidun Fauna, while the extremely dominant *Chilotherium* in the Late Miocene *Hipparion* fauna disappeared in this fauna. Other members of the Late Miocene *Hipparion* fauna, such as *Adcrocuta*, *Ictitherium* and *Chleuatochoerus* are absent in the Shilidun Fauna. *Chasmaporthetes* has a widespread distribution in the world, and its fossils were discovered from Europe, Asia, Africa, and North America; it first appeared in the Early Pliocene, corresponding to the Ruscinian Age of Europe. In China, *Chasmaporthetes* was discovered from Yushe and Shouyang in Shanxi, Nihewan in Hebei, and Mianchi in Henan (Qiu, 1987). In the Yushe Basin, *Chasmaporthetes* appeared first in the Gaozhuang Fauna with a paleomagnetic age of 5.2-3.4 Ma, when *Chilotherium* had disappeared (Qiu, 1987). The Gaozhuang Fauna should be correlated to MN14-15 of the European mammal ages (Qiu and Qiu, 1995). Kretzoi (1942) established a new genus *Shansirhinus* on the basis of *Rhinoceros brancoi* described by Schlosser (1903) as the type species, and renamed *Rhinoceros* aff. *R. brancoi* described by Ringström (1927) as *S. ringstromi*. *S. brancoi* does not have exact locality and horizon. *S. ringstromi* is collected from Huangshigou in the Nihe district of the Yushe Basin. Qiu et al. (1987a) indicated that the mammal fossils in the Nihe district came mainly from the Gaozhuang Formation, so the age of *S. ringstromi* should be Early Pliocene. Some common species of the Late Miocene *Hipparion* fauna, such as *Hystrix gansuensis*, *Cervavitus novorossiae*, and *Sinotragus* sp. still survived in the Shilidun Fauna, while the derived taxa in the Gaozhuang Fauna, such as *Ursus*, *Nyctereutes*, *Canis*, *Hipparion houfenense*, and *Sus* have not been found in the Shilidun Fauna. As a result, the age of the Shilidun Fauna may be early Early Pliocene, approximately corresponding to MN14.

5 Early Pleistocene *Equus* fauna

The Early Pleistocene Dongshan Formation is composed of lacustrine siltstones, but strata corresponding to the Lower Member of the Dongshan Formation in the east side of this basin is loess deposits, i. e., the Wucheng Loess (Fig. 2). The Early Pleistocene *Equus* fauna comes from the Wucheng Loess at Longdan in Dongxiang County, and its fossils include *Aepyosciurus orientalis*, *Marmota* sp., *Mimomys* cf. *gansunicus*, *Bahomys* sp., *Sericolagus brachypus*, *Macaca anderssoni*, *Paradolichopithecus* sp., *Vulpes chikushanensis*, *Canis* sp., *Meles* sp., *Chasmaporthetes progressus*, *Pachycrocuta licenti*, *Crocuta honanensis*, *Homotherium crenatidens*, *Megantereon nihowanense*, *Sivapanthera* sp., *Panthera*

palaeosinensis, *Felis teilhardi*, *Lynx shansius*, *Hipparion sinense*, *Equus* sp., *Coelodonta nihowanensis*, *Hesperotherium* sp., *Nipponicervus* sp., *Gazella* cf. *blacki*, *Leptobos brevicornis*, and *Hemibos* sp.

The existence of true horse and the absence of typical Middle Pleistocene forms, like *Pachycrocuta sinensis*, *Sinomegaceros*, *Bos* and *Bubalus*, immediately put the Longdan fauna in the Early Pleistocene. The Longdan Fauna is slightly older than that of the Nihewan Fauna (Teilhard and Piveteau, 1930) based on the following observations. Although congeneric, the evolutionary levels may be different. *Meles* sp., *Sivapanthera* sp. and *Gazella* cf. *blacki* of the Longdan fauna are certainly more primitive than their counterparts of the Nihewan fauna. Some primitive forms appeared in the Longdan fauna, but are absent in the Nihewan fauna, like *Panthera palaeosinensis*, *Leptobos brevicornis* and *Nipponicervus* sp. In Nihewan no *Panthera* and *Leptobos* were found, and *Cervus* (*Rusa*) *elegans* may be a more advanced species of *Nipponicervus*. On the other hand, a large number of more advanced forms, especially the cervids, appeared in the Nihewan Fauna, like *Axis shansius*, *Elaphurus bifurcatus*, *Eucladoceros boulei*, *Bison palaeosinensis*, *Paleoloxodon namadicus* etc. The extremely large horse, *Equus* sp. from Longdan, may be a horse species appeared earlier in age than *E. sanmeniensis* from Nihewan. Similar case can be seen in Europe, where the earliest horse, *E. livenzovensis*, is also larger than the typical Villafranchian horse, *E. stenonis*.

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References

Bohlin, B., 1937. Eine Tertiare Saugetier-Fauna aus Tsaidam. *Palaeontol. Sin.*, Ser. C, 14: 1–111.

Cerdeño, E., 1996. Rhinocerotidae from the Middle Miocene of the Tung-gur Formation, Inner Mongolia (China). *Am. Mus. Novit.*, 3184: 1–43.

Cerdeño, E., and Sánchez, B., 2000. Intraspecific variation and evolutionary trends of *Alicornops simorrense* (Rhinocerotidae) in Spain. *Zool. Scrip.*, 29: 275–305.

Deng, T., 2000. A new species of *Acerorhinus* (Perissodactyla, Rhinocerotidae) from the Late Miocene in Fugu, Shaanxi, China. *Vert. PalAsiat.*, 38: 203–217 (in Chinese with English summary).

Deng, T., 2001a. New materials of *Chilotherium wimani* (Perissodactyla, Rhinocerotidae) from the Late Miocene of Fugu, Shaanxi. *Vert. PalAsiat.*, 39: 129–138.

Deng, T., 2001b. Cranial ontogenesis of *Chilotherium wimani* (Perissodactyla, Rhinocerotidae). *Proc. Ann. Meet. Chinese Soc. Vert. Paleont.*, 8: 101–112.

Deng, T., 2001c. New remains of *Parelasmotherium* (Perissodactyla, Rhinocerotidae) from the Late Miocene in Dongxiang, Gansu, China. *Vert. PalAsiat.*, 39: 306–311.

Deng, T., 2003. New material of *Hispanotherium matritense* (Rhinocerotidae, Perissodactyla) from Laogou of Hezheng County (Gansu, China), with special reference to the Chinese Middle Miocene elasmotheres. *Geobios*, 36: 141–150.

Fang, X. M., Garzione, C., Van der Voo, R., Li, J. J., and Fan, M. J., 2003. Flexural subsidence by 29 Ma on the NE edge of Tibet from the magnetostratigraphy of Linxia Basin, China. *Earth Planet. Sci. Let.*, 210: 545–560.

Gansu Provincial Investigative Brigade (GPIB), 1965. *Introduction to 1 : 200000 Geological Map of the People's Republic of China (Linxia)*. Beijing: Geology Publishing House. 1–40 (in Chinese).

Guan, J., 1988. The Miocene strata and mammals from Tongxin, Ningxia and Guanghe, Gansu. *Mem. Beijing Nat. Hist. Mus.*, 42: 1–21 (in Chinese with English summary).

Heissig, K., 1969. Die Rhinocerotidae (Mammalia) aus der oberoligozänen Spaltenfüllung von Gaimersheim bei Ingolstadt in Bayern und ihre phylogenetische Stellung. *Bayer. Akad. Wiss. Math-Natur. Klas., Abh., Neu. Fol.*, 138: 1–133.

Heissig, K., 1976. Rhinocerotidae (Mammalia) aus der *Anchitherium*-Fauna Anatoliens. *Geol. Jahr.*, 19: 1–121.

Howell, F. C., and Petter, G., 1985. Comparative observations on some Middle and Upper Miocene hyaenids. *Geobios*, 18: 419–476.

Kretzoi, M., 1942. Bemerkungen zum System der nachmiozänen Nashorn-Gattungen. *Föld. Közl.*, 72: 4–12.

Li, C. K., 1978. Two new lagomorphs from the Miocene of Lantian, Shensi. *Profes. Pap. Stratigr. Palaeont.*, 7: 143–148 (in Chinese).

Li, C. K., Wu, W. Y., and Qiu, Z. D., 1984. Chinese Neogene: subdivision and correlation. *Vert. PalAsiat.*, 22: 163–178 (in Chinese with English summary).

Li, J. J., et al. , 1995. *Uplift of Qinghai-Xizang (Tibet) Plateau and Global Change*. Lanzhou: Lanzhou Univ. Press, 207.

Liu, T. S., Li, C. K., and Zhai, R. J., 1978. Pliocene vertebrates of Lantian, Shensi. *Profes. Pap. Stratigr. Palaeont.*, 7: 149–200 (in Chinese).

Qiu, Z. D., Li, C. K., and Wang, S. J., 1981. Miocene mammalian fossils from Xining Basin, Qinghai. *Vert. PalAsiat.*, 19: 156–173 (in Chinese with English summary).

Qiu, Z. X., 1987. Die Hyaeniden aus dem Ruscinium und Villafranchium Chinas. *Munchner. Geowiss. Abh.*, Reihe A, 9: 1–110.

Qiu, Z. X., and Guan, J., 1986. A lower molar of *Pliopithecus* from Tongxin, Ningxia Hui Autonomous Region. *Acta Anthropol. Sin.*, 5: 201–207 (in Chinese with English abstract).

Qiu, Z. X., Huang, W. L., and Guo, Z. H., 1987a. The Chinese hipparionine fossils. *Palaeont. Sin.*, New Ser. C, 25: 1–250 (in Chinese with English summary).

Qiu, Z. X., and Qiu, Z. D., 1995. Chronological sequence and subdivision of Chinese Neogene mammalian faunas. *Palaeogeogr. Palaeoclimat. Palaeoecol.*, 116: 41–70.

Qiu, Z. X., and Wang, B. Y., 1999. *Allacerops* (Rhinocerotoidea, Perissodactyla), its discovery in China and its systematic position. *Vert. PalAsiat.*, 37: 48–61 (in Chinese with English summary).

Qiu, Z. X., Wang, B. Y., and Xie, G. P., 2000. Preliminary report on a new genus of Ovibovinae from Hezheng district, Gansu, China. *Vert. PalAsiat.*, 38: 128–134 (in Chinese with English summary).

Qiu, Z. X., Wang, B. Y., and Xie, J. Y., 1998. Mid-Tertiary chalicothere (Perissodactyla) fossils from Lanzhou, Gansu, China. *Vert. PalAsiat.*, 36: 297–318 (in Chinese with English summary).

Qiu, Z., X, Wu, W. Y., and Qiu, Z. D., 1999. Miocene mammal faunal sequence of China: palaeozoogeography and Eurasian relationships. In: Rössner G E, Heissig K (eds.), *The Miocene Land Mammals of Europe*. München: Verlag Dr. Friedrich Pfeil, 443–455.

Qiu, Z. X., and Xie, J. Y., 1997. A new species of *Aprotodon* (Perissodactyla, Rhinocerotidae) from Lanzhou Basin, Gansu, China. *Vert. PalAsiat.*, 35: 250–267 (in Chinese with English summary).

Qiu, Z. X., and Xie, J. Y., 1998. Notes on *Parelasmotherium* and *Hipparion* fossils from Wangji, Dongxiang, Gansu. *Vert. PalAsiat.*, 36: 13–23 (in Chinese with English summary).

Qiu, Z. X., Xie, J. Y., Yan, D. F., 1987b. A new chilothere skull from Hezheng, Gansu, China, with special reference to the Chinese "*Diceratherium*". *Sci. Sin.*, (5): 545–552 (in Chinese).

Qiu, Z. X., Xie, J. Y., Yan, D. F., 1988. Discovery of the skull of *Dinocrocuta gigantea*. *Vert. PalAsiat.*, 26: 128–138 (in Chinese with English summary).

Qiu, Z. X., Xie, J. Y., and Yan, D. F., 1990. Discovery of some Early Miocene mammalian fossils from Dongxiang, Gansu. *Vert. PalAsiat.*, 28: 9–24 (in Chinese with English summary).

Qiu, Z. X., Xie, J. Y., and Yan, D. F., 1991. Discovery of Late Miocene *Agriotherium* from Jiegou, Gansu, and its taxonomic implications. *Vert. PalAsiat.*, 29: 286–295 (in Chinese with English summary).

Ringström, T., 1924. Nashorner der *Hipparion*-Fauna Nord-Chinas. *Palaeontol. Sin.*, Ser. C, 1 (4): 1–159.

Ringström, T., 1927. Über quartäre und jungtertiäre Rhinocerotiden aus China und der Mongolei. *Palaeont. Sin.*, Ser. C, 4 (3): 1–21.

Schlosser, M., 1903. Die fossilen Säugethiere Chinas nebst einer Odontographie der recenten Antilopen. *Abh. Kon. Bayer. Akad. Wissen.*, 22: 1–221.

Teilhard de Chardin, P., and Piveteau, J., 1930. Les mammiféres fossils de Nihowan (Chine). *Ann. Paléont.*, 19: 1–134.

Wang, B. Y., 2001. On Tsaganomyidae (Rodentia, Mammalia) of Asia. *Am. Mus. Novit.*, 3317: 1–50.

Wu, W. Y., Meng, J., and Ye, J., 2003. The discovery of *Pliopithecus* from northern Junggar Basin, Xinjiang. *Vert. PalAsiat.*, 41: 76–86.

Wu, W. Y., Ye, J., and Zhu, B. C., 1991. On *Alloptox* (Lagomorpha, Ochotonidae) from the Middle Miocene of Tongxin, Ningxia Hui Autonomous Region, China. *Vert. PalAsiat.*, 29: 204–229 (in Chinese with English summary).

Xie, J. Y., 1991. The Late Tertiary strata and mammalian fossils of Gansu, China. *J. Stratigr.*, 15: 36–41 (in Chinese).

Xue, X. X., Zhang, Y. X., and Yue, L. P., 1995. Discovery and chronological division of the *Hipparion* fauna in Laogaochuan Village, Fugu,County, Shaanxi. *Chinese Sci. Bull.*, 40: 926–929.

Yan, D. F., 1979. Einige der Fossilen Miozänen Säugetiere der Kreis von Fangxian in Der Provinz Hupei. *Vert. PalAsiat.*, 17: 189–199 (in Chinese with German summary).

Young, C. C., 1932. On a new ochotonid from north Suiyuan. *Bull. Geol. Soc. China*, 11: 255–258.

Zhai, R. J., 1978. A primitive elasmothere from the Miocene of Lintung, Shensi. *Profes. Pap. Stratigr. Palaeont.*, 7: 122–126 (in Chinese with English summary).

Zhang, Y. X., and Xue, X. X., 1996. New materials of *Dinocrocuta gigantea* found in Fugu County, Shaanxi Province. *Vert. PalAsiat.*, 34: 18–26 (in Chinese with English abstract).

Zhang, Z. Q., Gentry, A. W., Kaakinen, A., Liu, L. P., Lunkka, J. P., Qiu, Z. D., Sen, S., Scott, R. S., Werdelin, L., Zheng, S. H., and Fortelius, M., 2002. Land mammal faunal sequence of the Late Miocene of China: new evidence from Lantian, Shaanxi Province. *Vert. PalAsiat.*, 40: 165–176.

Zheng, S. H., 1980. The *Hipparion* fauna of Bulong Basin, Biru, Xizang. In: *Palaeontology of Xizang, Book 1*. Beijing: Science Press, 33–47 (in Chinese with English abstract).

Zheng, S. H., 1982. Some Pliocene mammalian fossils from Songshan-2 and -3 (Tianzhu, Gansu) and the Songshan Fauna. *Vert. PalAsiat.*, 20: 216–227 (in Chinese with English summary).